Navitas

Let’s go GaNFast™

GaNFast™ Power IC Modeling

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CPSSC, Nov 2019
• Introduction
• Spectre models for IC Design
• SPICE models for detailed system simulation
• SIMPLIS models for high level system simulation
• System simulation example: Active Clamp Flyback
• Conclusions
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Navitas eMode Power FET Technology

- Large RQ FOM advantage
  - High frequency, high power density
- Lateral
  - Convenient voltage isolation
  - Multi device and IC integration
- Standard CMOS production
  - High yield, high capacity, multilevel metallization
  - Ideal for power IC development
650 V Monolithic GaN Integration

World’s First
GaN Power ICs

• Complicated power IC development requires capable process and IC design environment
  • PDK (Process Design Kit) is essential to reliability and manufacturability of IC products
  • Process corners, mismatch, temperature effect, layout parasitic, and design verification
• Accurate device modeling is essential part of PDK
  • Multi tiered models are developed for accurate and fast system simulation
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Power IC Spectre Models: IC Development

• Excellent process design kit:
  • Device symbols
  • Pcells for automated device construction
  • Scalable, accurate
  • Verified for schematic and layout rules
  • Layout parasitic extraction

• Angelov, ASM and silicon models are not suitable
  • Lack of dMode, scalability, flexibility, speed

• Navitas GaN eMode FET scalable VerilogA model
  • Flexible: customized features/equations
  • High correlation between simulation and product
  • High-speed simulations
Accurate over Temperature

- GaN FET $I_DV_G$ Model with Temperature Effects
  - Solid lines = measured, dotted lines = Cadence simulation
Accurate over Drain Voltage

- Solid lines = measured, dotted lines = Cadence Spectre
- 20V rated eMode FET
- 650V rated eMode FET
Bi-directional Drain Current vs. $V_D$, $V_G$

650V device model simulation with self-heating effects in Spectre

Operation not allowed due to excess $V_{gd}$
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Spice Models: Application Simulation

Half Bridge Functional Blocks

- DZL & VDDL regulator & UVLO
- Bootstrap SW
- DZH & VDDH regulator & UVLO
- HS Gate Driver
- LS Gate Driver
- Input comp. & logic
- Parameters IPK, VPK, TC, etc.

Top-Level Model Parameters

<table>
<thead>
<tr>
<th>#</th>
<th>Parameter Name</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$V_{\text{CITH}}$</td>
<td>$V_{\text{CC}}$ Undervoltage Lockout Threshold</td>
<td>9.0</td>
<td>V</td>
</tr>
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<td>2</td>
<td>$V_{\text{CHYS}}$</td>
<td>$V_{\text{CC}}$ Undervoltage Lockout Hysteresis</td>
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<td>V</td>
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<td>$V_{\text{LTH}}$</td>
<td>$V_{\text{I}}$ Input Logic Threshold</td>
<td>2.5</td>
<td>V</td>
</tr>
<tr>
<td>4</td>
<td>$V_{\text{LHY}}$</td>
<td>$V_{\text{I}}$ Input Logic Hysteresis</td>
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<td>V</td>
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<tr>
<td>5</td>
<td>$V_{\text{BTH}}$</td>
<td>$V_{\text{B}}$ Undervoltage Lockout Threshold</td>
<td>9.0</td>
<td>V</td>
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<tr>
<td>6</td>
<td>$V_{\text{BHY}}$</td>
<td>$V_{\text{B}}$ Undervoltage Lockout Hysteresis</td>
<td>0.5</td>
<td>V</td>
</tr>
</tbody>
</table>

- Each Navitas power IC product will be released to public with a Spice model
- It captures all functionalities and behaviors
- Spice models combines Angelov and behavioral techniques
  - Fast and accurate
  - Ideal for detailed in-circuit waveform and power loss study
650V GaN eMode FET Output Curves

Datasheet:
\( I_D = 4A \)
\( V_{DS} = 720mV \)

\( I_D = 38A \)
\( V_{DS} = 10V \)
\( 25C \)

\( I_D = 18A \)
\( V_{DS} = 600V \)
\( 150C \)
Reverse Conduction Characteristics

- Third quadrant I-V curves at 25C and 150C under gate bias
- Synchronous drive reduces reverse conduction loss
Output Capacitance and Charge Simulation

Capacitance

- Coss 200pF full scale

Output Charge

- Qoss 26nC full scale

Model: 22pF @ 400V

Datasheet: 22pF @ 400V

Model: 20.0nC @ 400V

Datasheet: 20nC @ 400V

- Model matches the measurement in datasheet
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Optimized for system simulation run time

- Zener startup
- $V_{DD}$ regulator
- UVLO logic
- Gate Drive
- FET
Piece-wise Linear Model

- Nonlinear parameters are largely preserved: speed without loss of accuracy
Simplified Gate Driver

- Gate driver replaced by “Level 1” SIMPLIS native high-level gate driver block
- Driver parameters adjusted to meet timing of $T_r$, $T_f$
Simulated Switching Waveforms

6ns $V_{DS} t_r$
Max $dV/dt = 80$ V/ns
Load dependent

Adjustable fall time
$dV/dt$ 30-150 V/ns
Programming $R$ dependent
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Active Clamp Flyback & GaN IC: High Density ZVS

- **World’s smallest 27W USB-C**
- Available now from [amazon.com](http://amazon.com)

- **World’s smallest Charger 42W (30W-C + 18W-A) + Battery Pack (5,000 mAhr)**
- Available now from [Apple Store](https://www.apple.com/store)
ACF Simplis Models: Controller & GaN ICs

Very fast and accurate for startup, transient, line cycle ripple, etc.

Schematic from Texas Instruments. System jointly developed with Navitas
Detailed and accurate enough for system optimization

$V_{SW}$ is half-bridge midpoint
  - Detailed soft switching waveforms

$I_{SEC}$ SR current
  - Rms current analysis and reduction

$I_{PRI}$ transformer current
  - Minimize negative current to achieve ZVS and reduce rms
Various modes of operation can be observed and analyzed during startup
  - Current limit mode, burst mode, ACF mode, Vout transient
Simplis Sim Example: Load Transient

- $I_o$ steps from full load to half load
- $V_{OUT}$ rises due to response delay
- Settles down by entering into burst mode
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Conclusions

- eMode GaN is suitable for power IC integration
- Proprietary PDK for robust GaN Power IC design and manufacture
- Accurate multi-tier models are developed
- Advanced, highly-accurate, 4-terminal symmetric, scalable GaN FET Verilog model for IC design
- Accurate SPICE model for each product is essential for optimal accuracy
- SIMplis models also available for released products for ultra fast top level system design
- GaNFast™ Power ICs are successfully developed and in mass production